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THERMAL DISCHARGE DISPLACEMENT OF SIMULATED LITTORAL DRIFT FISH LARVAE

Report No 85-40-K

W.E. Carey
Biologist
Biological Research Section
Chemical Research Department

ABSTRACT

A series of drift tube releases was conducted in the vicinity of Bruce GS 'A' discharge. For upstream releases, offshore displacement of drift tubes was inversely related to the distance from shore at which the tubes were released, and occurred within the convergence zone of the thermal plume and the ambient lake current.

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740634-108-492	837.315	March 12, 1985	85-40-K

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EXECUTIVE SUMMARY

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At the request of Design and Development Division a study forming part of the Capitalized-Once-Through-Cooling (COTC) program was conducted on the potential for offshore deflection of simulated fish larvae by the Bruce GS 'A' thermal plume. The study objective was to derive empirical data on offshore displacement distances and trajectories of simulated fish larvae drifting in longshore surface currents. This information would be used to assist the development of a mathematical model to predict the offshore displacement of littoral zone fish larvae.

A series of drift tube releases near Bruce GS 'A' discharge during a predominantly northeast longshore current demonstrated that offshore displacement was inversely related to the distance from shore of upstream releases. Shifts in wind and lake current direction strongly influenced the pattern of sequential drift tube trajectories. Drift tubes released inshore were displaced offshore within a zone defining the convergence of the thermal plume and the surface ambient lake current. The period of offshore displacement during tracking ranged from 50-80 min. Drift tube speeds reflected both the strong influence of the thermal plume inshore and the major influence of the ambient surface current offshore. Downstream releases made during northeast current conditions resulted in less offshore movement of drift tubes than upstream releases.

The development of a model capable of predicting offshore displacement of fish larvae by a thermal plume should take into account the path of offshore deflection within the plume and the changes in wind and current magnitude and direction that occur during the displacement process.

for WC

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To Mr. C.W. Dawson
Section Head
Environmental Sciences and Technology
Design & Development Division

THERMAL DISCHARGE DISPLACEMENT OF SIMULATED LITTORAL DRIFT FISH LARVAE

1.0 INTRODUCTION

The predominance of longshore currents in the nearshore areas of Lake Huron and Lake Ontario (Ontario Hydro Design and Development Division Report Nos 82393 and 83208) suggests that fish larvae produced within the littoral zone of these lakes are normally subject to substantial shore-parallel transport. Offshore displacement of fish larvae may occur when a thermal discharge flow interacts with ambient longshore currents.

Design and Development Division, as part of the COTC program, is developing a generic model to predict the offshore displacement of larval fish by a thermal discharge (Raithby, 1984). Based on the preliminary modelling results for Bruce GS 'A' it was concluded that for currents directed towards the northeast only local changes in the trajectory of fish larvae would occur, whereas during southwesterly currents significant offshore displacement of fish larvae would be observed. In particular it was predicted that for upstream releases made during a northeast current the Bruce GS 'A' discharge would cause the dilution of fish concentrations released close to shore and minimal disturbance of fish concentration contours farther offshore (Raithby, 1984).

This study was undertaken at the request of Environmental Studies and Assessments Department of Design and Development Division. It was conducted in the vicinity of Bruce GS 'A' discharge on the eastern shore of Lake Huron. The objective of the study was to evaluate initial model predictions by obtaining empirical information on displacement distances and trajectories of simulated fish larvae in the field.

Since thermal plumes are normally buoyant during the periods when larval fish are present, only surface phenomena were considered. It was assumed that the offshore advection of drifting artificial devices by a thermal plume would adequately represent offshore displacement of fish larvae entrained in a discharge flow. This assumption seems reasonable since the swimming velocity of a larval fish is insignificant relative to the velocity of a discharge plume.

2.0 METHODS

Sealed plastic (ABS) drift tubes 10.0 cm high x 2.5 cm inside diameter were used to simulate drifting fish larvae, and were tracked by means of radiotelemetry. Each tube was prepared as follows. An AVM Instrument Company transmitter tuned in water to a frequency of 50.2 - 50.4 MHz was connected to a 2.7 V mercury battery and inserted into and fixed in a plastic tube, which was then capped (plastic cap) and sealed with silicone. For the majority of trials an SB2 transmitter was used. However, a Unit B temperature sender was used once when an SB2 unit was malfunctioning. Each sealed tube was designed to have a positive buoyancy such that the top of the tube was nearly flush with the water surface. Tubes were painted bright orange to aid in retrieval and were numbered for identification purposes.

The receiving system consisted of a boat-mounted four-element Yagi antenna (Cushcraft Co) and an LA12 portable receiver (AVM Instrument Co) which had an array of 12 pre-set frequency channels. Nine (9) channels were selected to receive signals from nine transmitters simultaneously.

Drift tube release points are shown in Figure 1. In all the surveys the ambient nearshore surface current was directed approximately to the northeast, a condition which usually results in a thermal plume oriented alongshore to the northeast (Ontario Hydro Design and Development Division Report No 83336). Three (3) drift tubes were released at each point according to the schedule presented in Table 1. A total of 45 drift tubes was released. Distances of release points from the discharge were similar to some of those used in previous model simulations (Raithby, 1984).

Subsequent to release drift tubes were tracked and periodic position fixes were obtained (including initial positions of tubes) using a Loran C navigational system. The frequency of position fixing was determined by the number of drift tubes in the water (usually three at one time) and by the condition of the lake (the tracking boat, a Boston Whaler, could not be safely operated in rough weather with the installed receiving equipment). The number of position fixes depended upon the

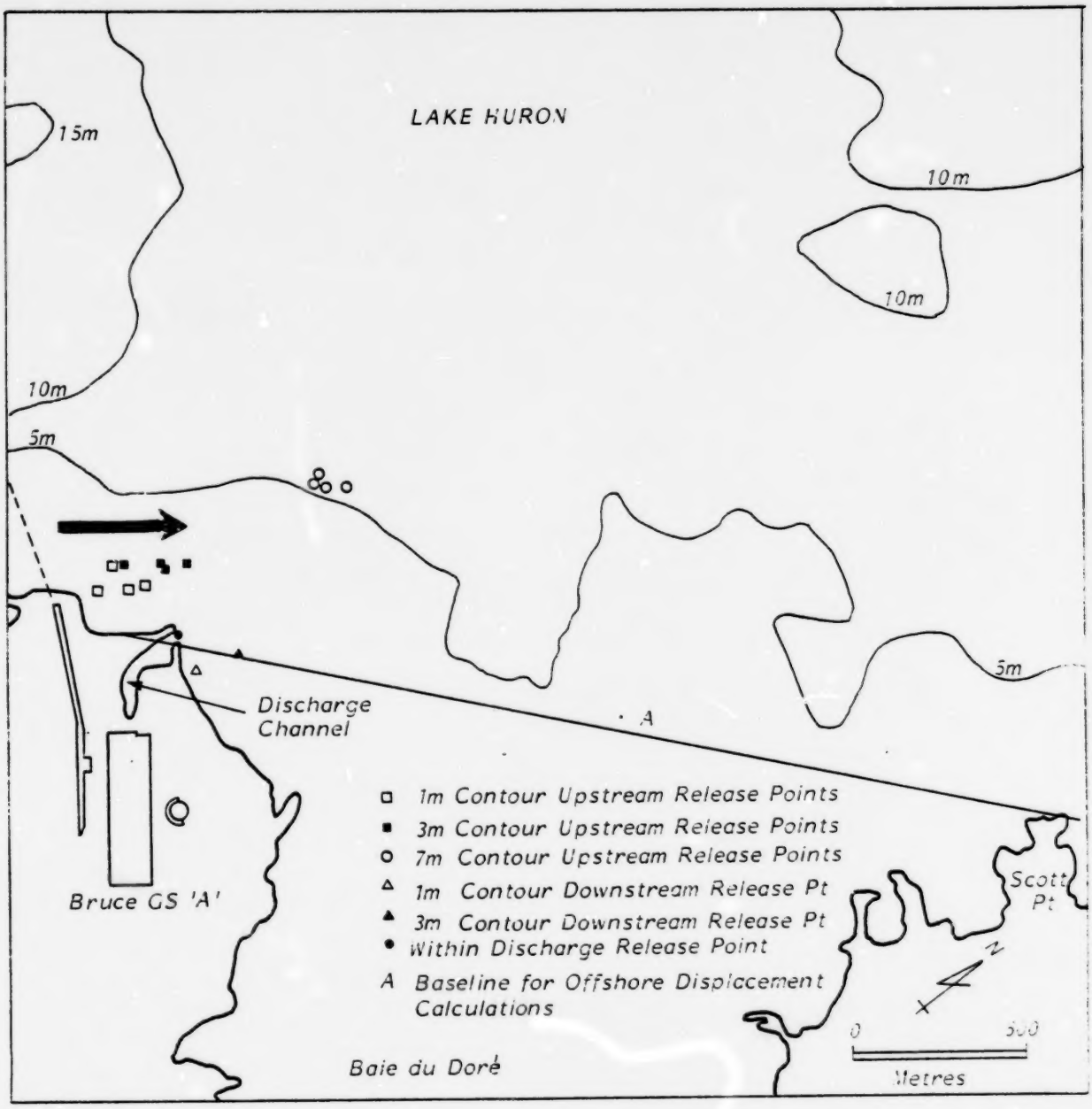

FIGURE 1

DRIFT TUBE RELEASE POINTS FOR A NORTHEASTERLY SHORE-PARALLEL CURRENT FLOW (DARK ARROW). CONTOURS ARE INDICATED. THREE (3) DRIFT TUBES WERE RELEASED AT EACH POINT

TABLE 1

SUMMARY OF DRIFT TUBE DISPLACEMENT TRIALS

Date	Contour (m)	Approximate Distance from Discharge Centreline (m)	Number of Drift Tubes	Number of Position Fixes
*UPSTREAM RELEASE POINTS				
August 28	1	50	3	7
	1	100	3	6
	1	150	3	3
September 7	1	150	3	7
August 29	3	50	3	5-6
	3	100	3	5
	3	150	3	5
September 7	3	150	3	7
August 30	7	50	3	7-8
	7	100	3	7
	7	150	3	7
September 7	7	150	3	5
*DOWNSTREAM RELEASE POINTS				
August 29	1	100	3	3
	3	150	3	5
WITHIN DISCHARGE RELEASE POINT				
August 30	3	0	3	5

* Upstream and downstream release points are relative to the ambient surface longshore current (see Figure 1).

length of time taken to obtain a single fix, which varied from 1 - 20 min. At each position fix, the amount of elapsed time was recorded.

Wind speed ($km \cdot h^{-1}$) and direction data (August 28-29 and September 7, 1984) was obtained from Hydraulic Studies and Development (HSD) Department. Wind speed and direction were estimated on August 30, 1984. Magnitude ($cm \cdot s^{-1}$) and direction of the ambient current were obtained on each sampling day by means of surface drogue measurements. Limited water temperature data was recorded on August 30 and September 7, 1984.

After generating a Loran C grid map based on readings taken at several known locations (two shoreline and one at a HSD Bruce GS 'A' construction grid location), drift tube trajectories were plotted. Mean drift tube speeds (n=3) were calculated for each track segment (distance between position fixes) and plotted against the mean cumulative time. To obtain a relative measure of the net distance that each drift tube was displaced offshore (OD), the difference was taken between the final and initial perpendicular distance (m) of each tube from an imaginary straight line approximating the shoreline aspect. This line passed through Scott Point and the northeast groin of the Bruce GS 'A' discharge (Figure 1). Alongshore displacement (AD) was calculated and compared to offshore displacement (OD) by obtaining the displacement ratio (AD/OD).

Bruce GS 'A' Units 1, 3 and 4 were operational during the study, and discharge flow rates ranged from 155 - 160 $m^3 \cdot s^{-1}$ on the test dates.

3.0 RESULTS AND DISCUSSION

Data summaries are contained in Appendices 1 and 2.

A. Drift Tube Trajectories

August 28, 1984

There was an obvious deflection of drift tubes released upstream (relative to the ambient longshore current) of the Bruce GS 'A' discharge on August 28, 1984 (Figure 2). The ambient surface current was directed to the northeast with an estimated speed of 9.3 $cm \cdot s^{-1}$, measured at the 3 m contour (Figure 2). Wind was blowing from the southwest at gusts of up to 26 $km \cdot h^{-1}$ (Table 2). As a result of these wind and current conditions all drift tubes moved initially towards the discharge plume. Tubes were subsequently deflected offshore by the thermal plume. The trajectories of drift tubes released approximately 50 m and 100 m upstream of the Bruce GS 'A' discharge showed a second,

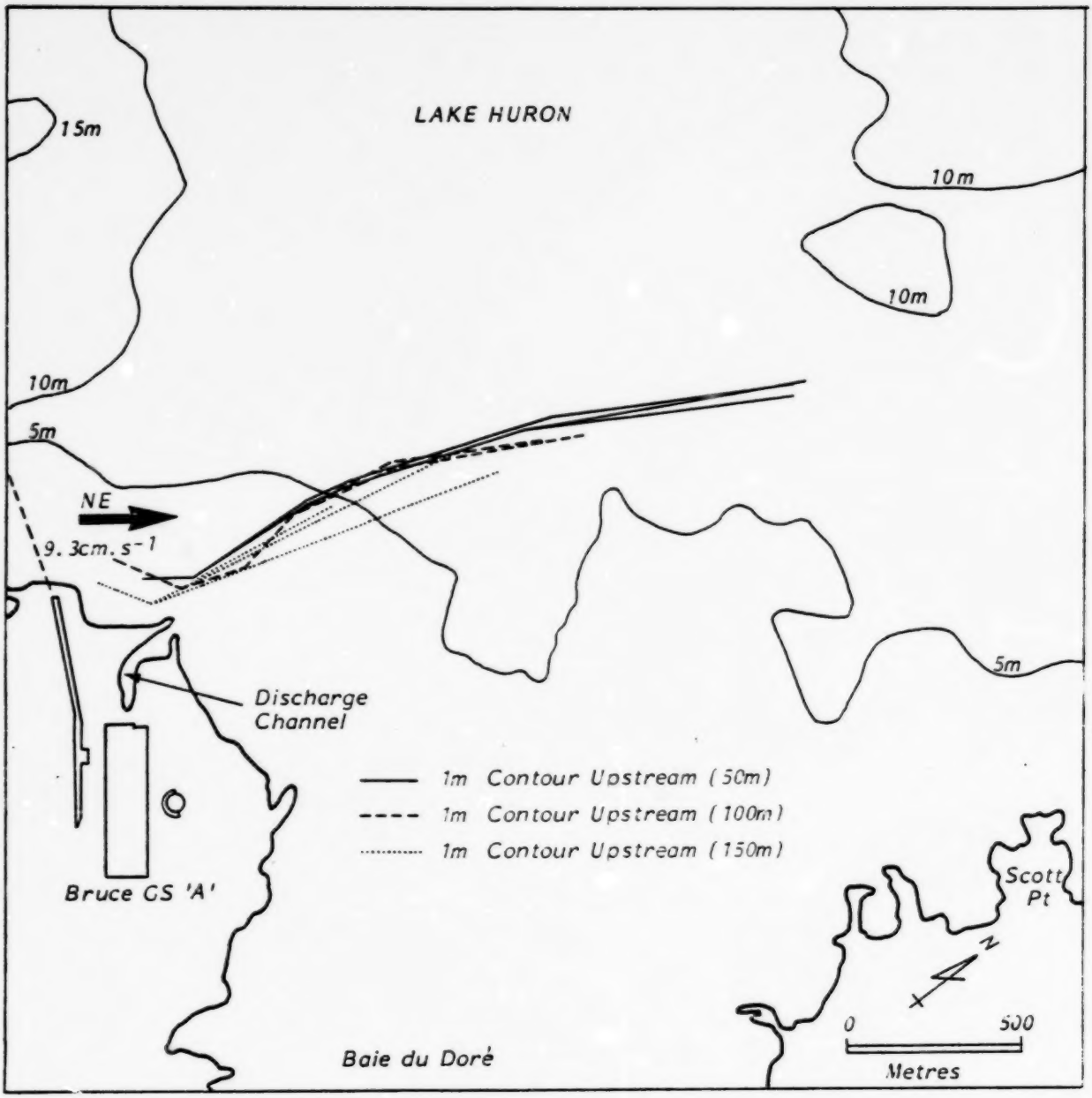

FIGURE 2

DRIFT TUBE TRAJECTORIES ON AUGUST 28, 1984

TABLE 2

WIND AND SURFACE CURRENT DATA

Date	Time of Day (h)	Wind Speed ($km \cdot h^{-1}$)	Wind Direction (from)	Current Speed ($cm \cdot s^{-1}$)	Current Direction (to)
August 28	0800	16	SSW		
	0900	21	SW		
	1000	25	SW	9.3 (3 m contour)	NE
	1100	26	SW		
	1200	23	SW		
	1300	23	SW		
	1400	20	SW		
	1500	9	SSW		
August 29	0800	17	SSW	8.7 (3 m contour)	NNE
	0900	17	SW		
	1000	15	SSW		
	1100	15	SSW		
	1200	17	SSW		
	1300	20	SW		
	1400	22	SW		
	1500	23	SW		
August 30	1000	15-20*	WSW*	11.8 (3 m contour)	ENE
				21.9 (7 m contour)	ENE
September 7	0800	13	SE	13.9 (3 m contour)	NNE
	0900	15	SE	24.8 (7 m contour)	NNE
	1000	12	SSE		
	1100	18	SSW		
	1200	11	SSW		
	1300	20	SSW		
	1400	13	SSW		
	1500	9	SSW		

* Estimated values

less pronounced deflection between the 5 m and 7 m contours, resulting in drift tubes having a compass bearing of NNE (Figure 2). Strong winds prevented completion of the trial in which drift tubes were released about 150 m upstream of the discharge. However, the trajectories of these tubes were different from the previous ones (50 m and 100 m release points), in that the angle of path deflection was less and drift tubes did not remain close together. The maximum distance separating tubes released 150 m upstream of the discharge was 500 m, recorded at the last position-fixing location for these tubes.

August 29, 1984

The trajectories of drift tubes released on August 29, 1984 are presented in Figure 3. The direction of the surface ambient current had shifted slightly towards the north (NNE) in response to a wind from the SSW during the morning trials. In the afternoon the wind was again originating in the southwest (Table 2). Paths of drift tubes released upstream of the discharge reflected the shift in wind direction and (presumably) the plume direction. Although all tubes were released along the 3 m contour, trajectories differed according to both the chronological order and position of release. Tubes released 50 m upstream of the discharge, which were released first, were deflected the farthest and were directed offshore to the north, roughly parallel to the discharge centreline. Trials involving the release of drift tubes 100 m upstream of the discharge were conducted second and resulted in tubes being displaced offshore to a lesser degree than the 50 m tubes. The final set of tubes released upstream (150 m) on August 29 followed a course which was oriented more alongshore (and less offshore) than either the 100 m or 50 m tubes (Figure 3). Thus the upstream drift tube releases were associated with trajectories which corresponded with both wind and current directions.

A downstream release of drift tubes 100 m from the discharge along the 1 m contour did not result in substantial offshore movement of tubes, which drifted towards the mouth of Baie du Dore. Greater offshore displacement occurred for the second set of drift tubes released 150 m downstream of the discharge along the 3 m contour (Figure 3). These tubes were displaced a considerable distance alongshore and by the end of the trial were located at about the 5 m contour off Scott Point. It is possible that these drift tubes were being moved along by a mass of water entrained into the downstream (with respect to the ambient current) edge of the thermal plume.

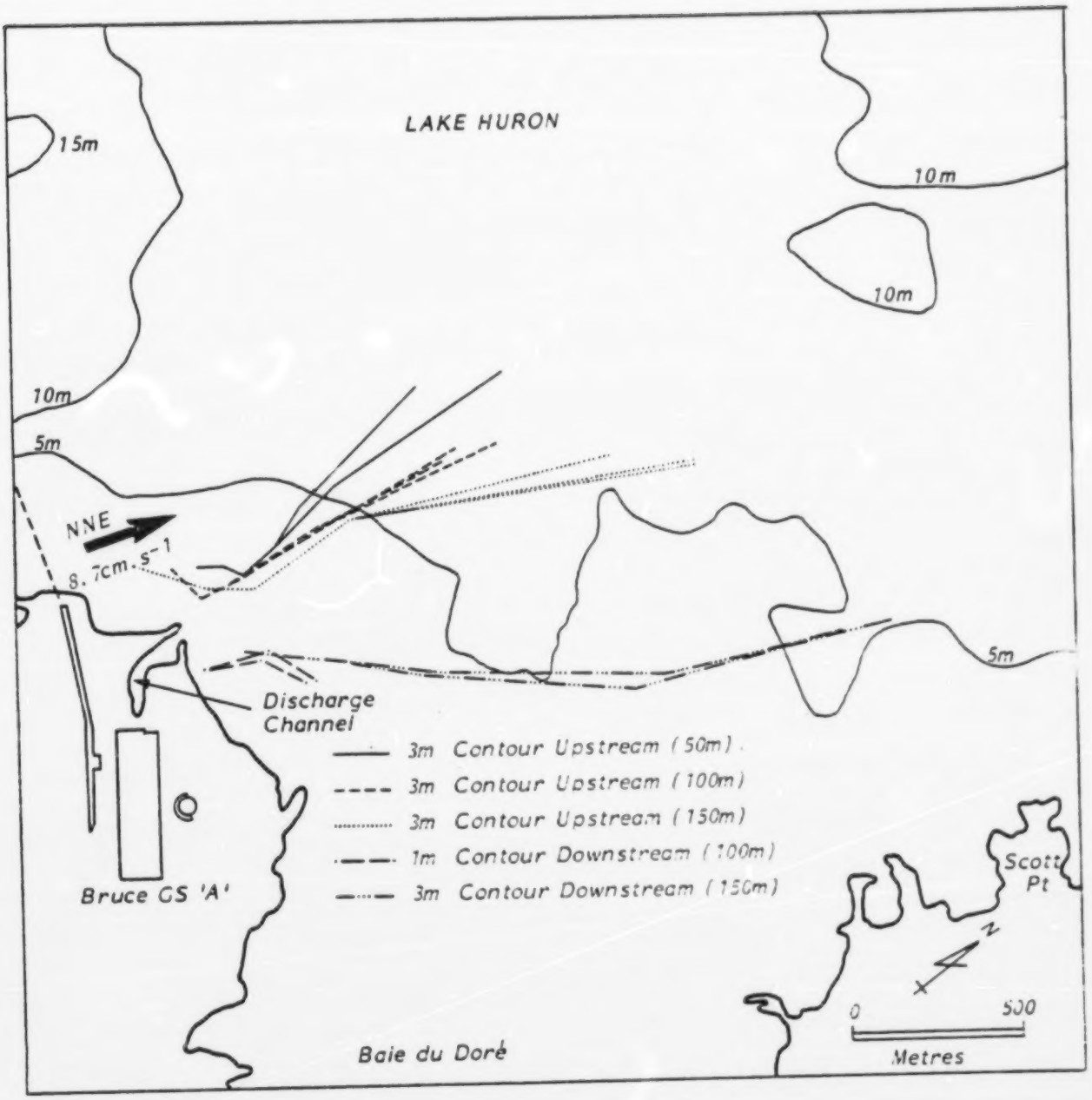

FIGURE 3

DRIFT TUBE TRAJECTORIES ON AUGUST 29, 1984

167282 RD

August 30, 1984

Current direction again shifted on August 30, 1984, with drogue measurements indicating an ENE surface current. Wind data was unavailable on that sampling day, but the wind was estimated to be from WSW at 15-20 $km \cdot h^{-1}$, corresponding to the current direction. Observed trajectories of sequentially released groups of drift tubes suggest that plume direction (thus wind direction) changed during upstream trials. The final positions of drift tubes released during the August 30 tracking periods was such that tubes released 150 m upstream of the discharge were farthest from shore, tubes released 50 m upstream of the discharge were nearest to shore, and 100 m tubes were intermediate in position between the 50 m and 150 m tubes (Figure 4). A prominent feature of the August 30 trials was that the resulting drift tube trajectories were directed mainly alongshore, with little evidence of offshore deflection (Figure 4). This result is probably related to the fact that on August 30 all upstream release points were along the 7 m contour, where the momentum of the discharge was less than that at the 1 m or 3 m contours. Drift tubes released together had separated by about 50 m at the end of the three upstream trials (Figure 4).

The path followed by drift tubes released at the end of the discharge groins (release prior to upstream tube releases) is particularly interesting. After initially being displacedoffshore in a N to NNE direction by the thermal plume, these drift tubes were strongly deflected by the surface current to an ENE orientation that resulted in movement towards Baie du Dore (Figure 4). There was a marked separation (about 150 m) among drift tubes as they approached the outer reaches of the bay. This apparent dispersal of drift tubes could have been caused by local changes in plume configuration. Alternatively, the momentum of the plume may have been minimal at the mouth of the Bay.

September 7, 1984

The pattern of drift tube trajectories obtained on September 7, 1984 (Figure 5) was similar to that observed on August 28, 1984 (Figure 2). Drift tubes released 150 m upstream of the discharge along the 1 m, 3 m and 7 m contours moved alongshore first, then were displaced offshore under the influence of the thermal plume. The surface current measured 13.9 $cm \cdot s^{-1}$ at the 3 m contour and was directed to the NNE (Figure 5), corresponding with the predominant wind direction (from SSW) during trials (Table 2).

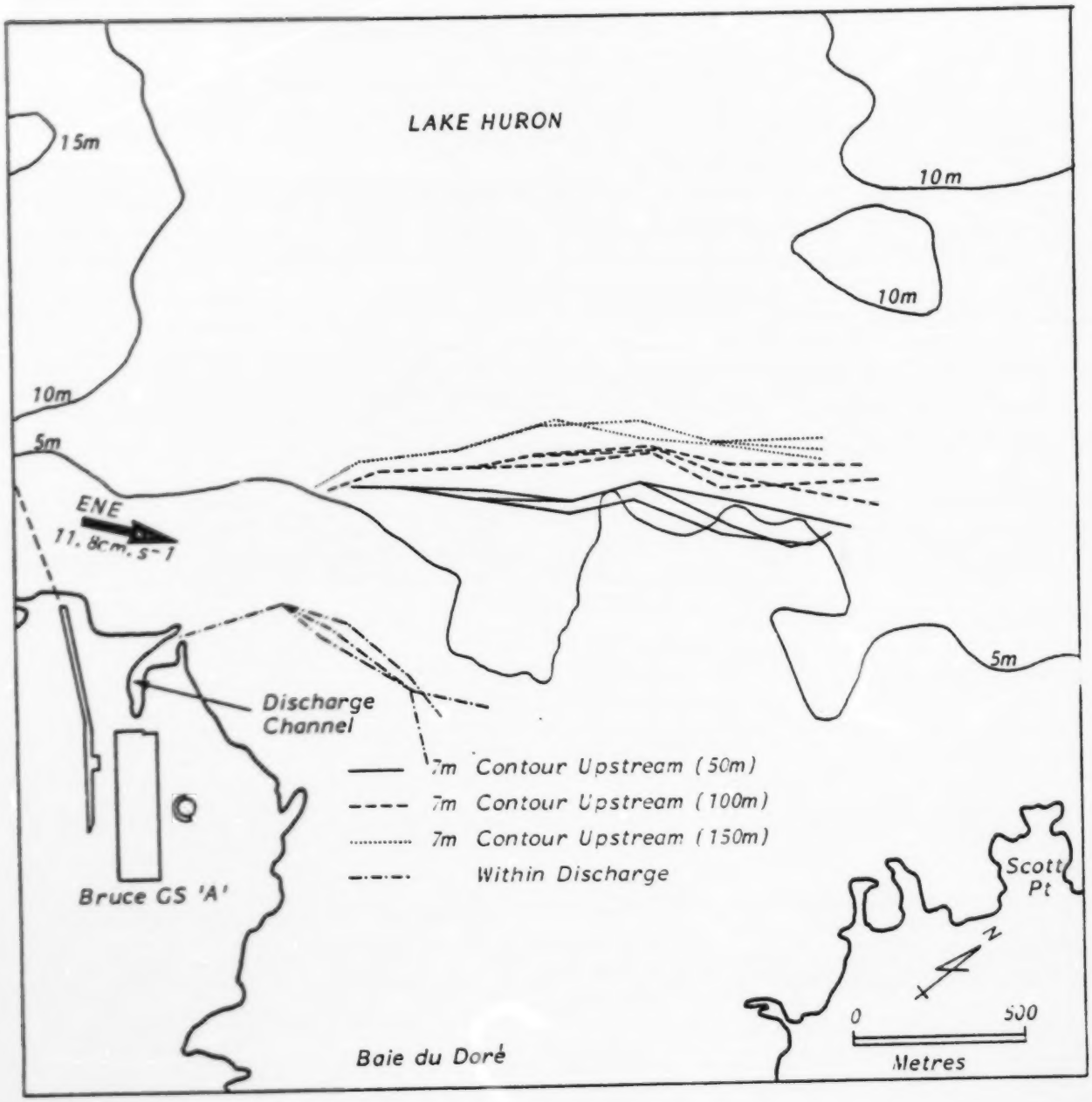

FIGURE 4

DRIFT TUBE TRAJECTORIES ON AUGUST 30, 1984

167283 RD

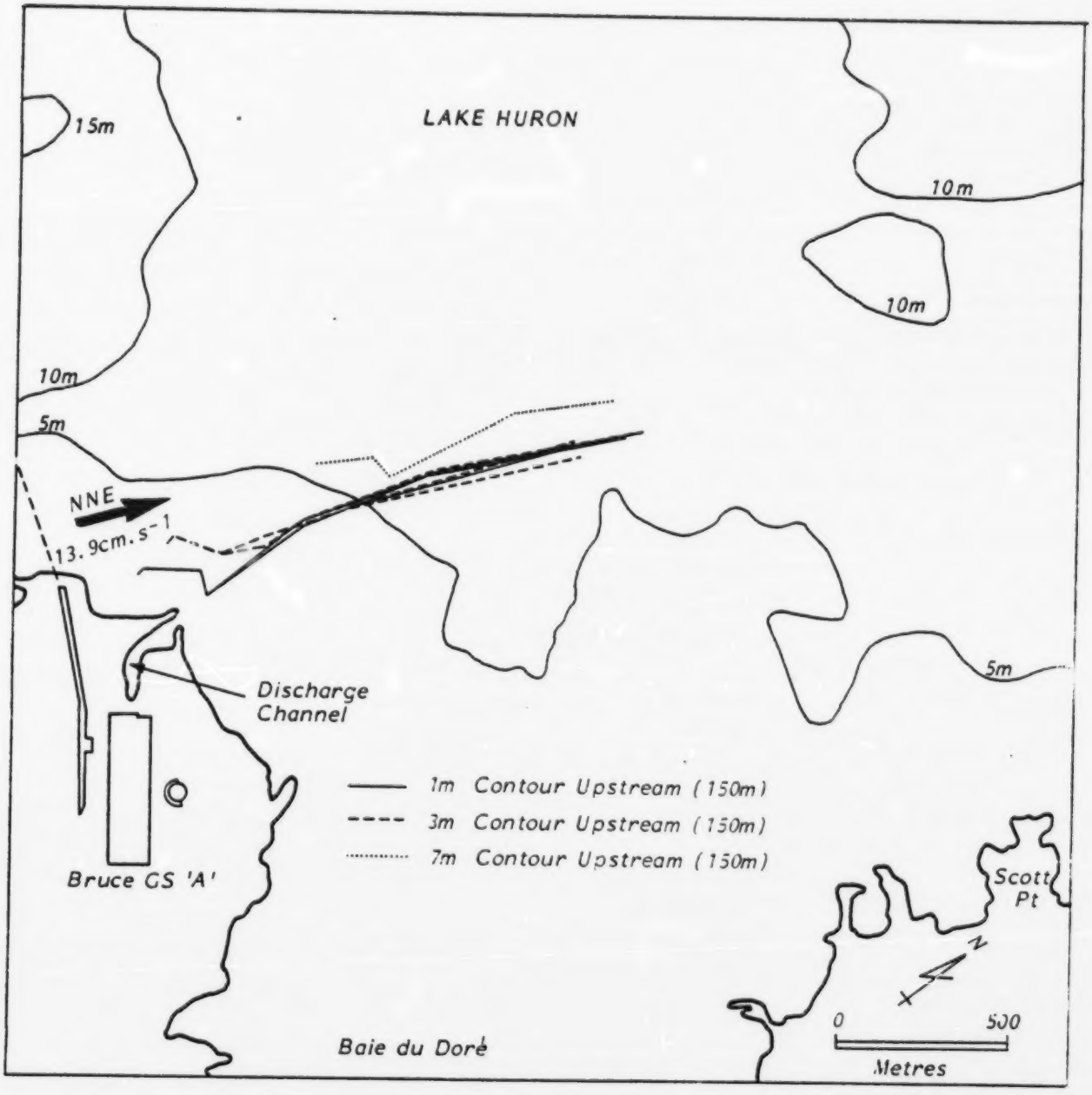

FIGURE 5
DRIFT TUBE TRAJECTORIES ON SEPTEMBER 7, 1984

Drift tube releases occurred within 5 min of each other and consequently may be considered as simultaneous releases. It is important to note that drift tubes released at the 1 m contour had trajectories that overlapped those of tubes released at the 3 m contour. Further, the paths of the 1 m and 3 m tubes ultimately became parallel to that of drift tubes released at the 7 m contour and resulted in a distance of about 100 - 200 m between all tubes at the end of the trials (Figure 5). The complete overlapping of all drift tube trajectories monitored on September 7 probably did not occur because of a difference in surface ambient current speeds recorded at the 3 m and 7 m contours. Although the direction of these currents was similar the current at the 7 m contour was higher in magnitude (24.8 $cm \cdot s^{-1}$) than that at the 3 m contour (13.9 $cm \cdot s^{-1}$) (Table 2). Consequently, drift tubes released at the 7 m contour were displaced far enough offshore from their original position (presumably by both the thermal plume and the surface current) that trajectories of 1 m and 3 m contour drift tubes were distinct from those of 7 m contour drift tubes (Figure 5).

All Releases

It was observed during the majority of upstream trials that drift tubes travelled offshore along the upstream boundary of the thermal plume. This phenomenon was more characteristic of 1 m and 3 m contour releases than of 7 m contour releases. The area where the upstream edge of the thermal plume (with respect to ambient current) interacted with the surface lake current may be described as a zone of convergence, which was about 10 - 15 m wide at any point along its length. Within the convergence zone the lake surface was smooth, giving the appearance of calm water. In contrast the adjacent plume and lake waters were rough. Organic matter and littoral debris occurred in the convergence zone, forming a line parallel to its long axis. The convergence zone appeared to be an area of downwelling caused by the collision of the ambient lake current and thermal plume water masses, and resembled a line of surface convergence normally associated with Langmuir circulation, in which zones of surface convergence alternate with zones of upwelling.

Surface temperature was recorded at two locations on August 30. Near the end of the discharge groins, plume and ambient upcurrent lake temperatures were 27.5°C and 21.0°C, respectively. Along the 7 m contour plume temperature was 24.5°C compared with 22.6°C for ambient upcurrent lake water. Surface temperature measurements taken across the convergence zone (3 m contour) on September 7 revealed a strong thermal gradient with temperatures ranging from 15.5°C upstream of the plume to 23.5°C within the plume. At the center of the convergence zone, which spanned

approximately 15 m, water temperature was 18.0°C. No convergence zone was apparent at the 7 m contour, where surface temperatures ranged from 15.5°C upstream of the plume to 20.5°C in the plume. This thermal gradient extended over a distance of about 500 m.

Overall, these observations indicate that in the thermal plume near-field area where strong thermal gradients existed, the path of offshore displacement of upstream-released drift tubes was along the line of convergence of the thermal plume and the longshore current. Farther offshore the thermal gradient was not well-defined, little or no convergence zone formed, and drift tube movement was determined mainly by the magnitude and direction of the prevailing lake current. All upstream-released drift tubes except those released at the 7 m contour on August 30 still had an offshore component of movement during the final tracking interval of the respective trials (Figures 2, 3 and 5). Thus, further offshore displacement was possible but not recorded.

B. Extent of Offshore Displacement

Table 3 presents the alongshore displacement (AD) and offshore displacement (OD) of drift tubes. Generally displacement of drift tubes alongshore exceeded that occurring in an offshore direction. For each tube released upstream along the 1 m contour the AD/OD displacement ratio was about 2:1 regardless of the proximity of release points to the thermal plume (Table 3). Similar displacement ratios were obtained for drift tubes released along the 3 m contour except for those released 50 m upstream of the plume. The latter tubes each had approximately a 1:1 displacement ratio. As noted in the previous section the greater offshore component of movement displayed by drift tubes released 50 m upstream at the 3 m contour was caused by a NNE lake current driven by wind from the SSW. It is surmised that a low displacement ratio (<1.0) would be associated with the maximum amount of offshore displacement, which would occur when the Bruce GS 'A' thermal plume and ambient lake current directions coincide (northerly direction) and their speeds are thus additive. Displacement ratios for tubes released upstream along the 7 m contour on August 30 decreased as the release distance increased (Table 3). This apparent inverse relationship was probably caused by a change in wind (and hence current) direction between August 29-30 (Table 2). A 2:1 displacement ratio was obtained for each drift tube released along the 7 m contour on September 7.

TABLE 3

OFFSHORE AND ALONGSHORE DISPLACEMENT OF DRIFT TUBES

UPSTREAM RELEASES										
Distance from Discharge	Tube No	1 m Contour			3 m Contour			7 m Contour		
		AD	OD	DR	AD	OD	DR	AD	OD	DR
50 m	1	1721	917	1.9	358	300	1.2	451	154	9.4
	2	1764	908	1.9	783	725	1.1	1364	92	14.8
	3	1745	870	2.0	542	634	0.9	1394	127	11.0
100 m	1	1134	566	2.0	750	483	1.6	1514	372	4.1
	2	1261	608	2.1	862	525	1.6	1565	334	4.7
	3	1134	566	2.0	739	453	1.6	1578	264	6.0
150 m	1	943	567	1.7	1303	558	2.3	1420	400	3.6
	2	1075	534	2.0	1562	583	2.7	1410	432	3.3
	3	611	342	1.8	1540	493	2.6	1412	367	3.8
150 m	1	1177	644	1.8	1043	642	1.6	801	375	2.1
	2	1312	694	1.9	1232	700	1.8	801	375	2.1
	3	1341	710	1.9	1076	604	1.8	801	375	2.1
		$\bar{X}$ = 661			$\bar{X}$ = 567			$\bar{X}$ = 306		

DOWNSTREAM RELEASES					
Distance from Discharge	Tube No	AD	OD	DR	
100 m	1	282	23	12.3	1 m Contour
	2	332	30	11.1	
	3	332	30	11.1	
150 m	1	1693	375	4.5	3 m Contour
	2	1655	350	4.7	
	3	1842	434	4.2	

DISCHARGE RELEASE			
Tube No	AD	OD*	DR
1	772	-240	-3.2
2	786	-98	-8.0
3	916	-51	-18.0

AD = Alongshore Displacement (m); OD = Offshore Displacement (m)
DR = Displacement Ratio (AD/OD)
* a negative OD indicates movement towards Baie du Dore

$\bar{X}$ = the mean offshore displacement distance for upstream releases made along a single contour (one value for each contour)

Drift tubes released downstream of the discharge at the 1 m contour moved alongshore but exhibited little offshore displacement as indicated by high displacement ratios (Table 3). Tubes released downstream at the 3 m contour were displaced at least 1600 m alongshore and about 400 m offshore (Table 3). This result clearly demonstrates that drift tubes released on the downstream side of a thermal plume can be advected offshore, possibly by entrainment along the downstream edge of the plume. Discharge-released drift tubes were ultimately displaced between 51 m and 240 m onshore (ie, towards Baie du Dore) as indicated by the negative displacement values (Table 3).

There was a highly significant difference ($P<0.001$; $F_{2,33} = 21.59$) observed in the mean distance that drift tubes were displaced offshore relative to the contour at which the tubes were released. For drift tubes released upstream along each contour the order of mean offshore displacement was 1 m > 3 m > 7 m (Table 3). This result strongly indicates that an inverse relationship existed between offshore displacement and the distance that tubes were released from shore, corresponding to a reduction in plume momentum with increasing distance from shore.

C. Speed and Duration of Offshore Displacement

Upstream

The speed of offshore movement of drift tubes released upstream of the plume was not constant through time (Figure 6). Initial mean speeds of drift tubes were representative of ambient lake current speeds as the tubes approached the thermal plume and ranged from 5 - 14 $cm \cdot s^{-1}$ for tubes at the 1 m and 3 m contours and from 15 - 35 $cm \cdot s^{-1}$ for tubes at the 7 m contour. Higher surface lake current speeds were measured at the 7 m contour than at the 1 m and 3 m contours (Table 2), and likely influenced the speed of drift tubes displaced offshore.

The mean speeds of drift tubes released at 1 m and 3 m contours increased sharply when these tubes encountered the thermal plume, about 45 - 60 min after release (Figure 6). Except for drift tubes released on September 7, tubes released at the 7 m contour had mean speeds which were relatively constant (about 30 $cm \cdot s^{-1}$) during the later portions of the trials. These tubes were probably affected more by the ENE longshore current than by the thermal plume on August 30. Drift tubes released at the 7 m contour on September 7 had a very high mean speed (almost 45 $cm \cdot s^{-1}$) during the middle portion of the trajectory (Figures 5 and 6). This high mean drift tube speed was probably due to the combination of a strong NNE ambient current at the 7 m contour and a northerly directed thermal plume. Near the end of the 7 m contour trial on September 7, when drift tubes

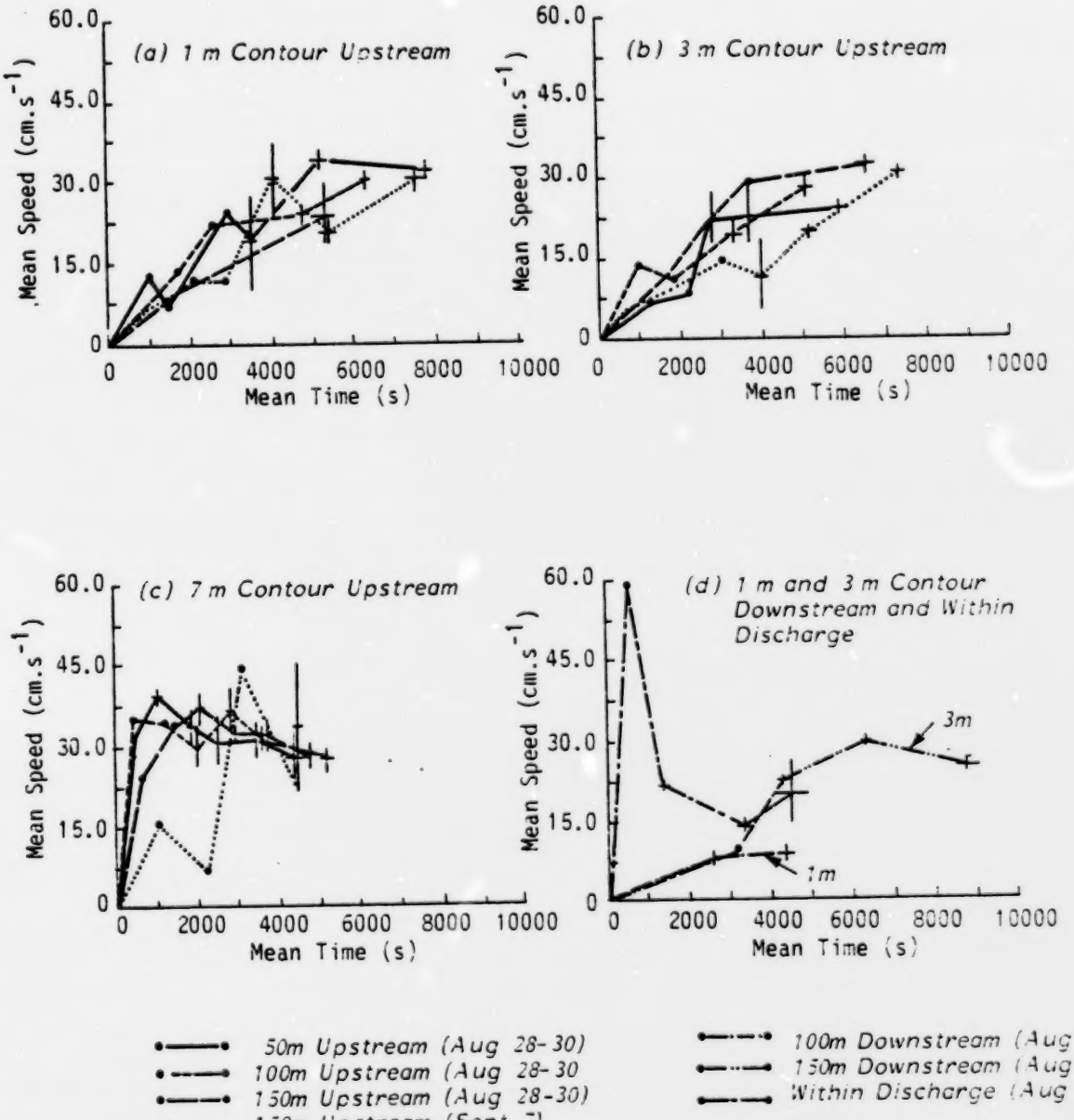

FIGURE 6

COMPARISON OF MEAN (± SD) DRIFT TUBE SPEEDS VERSUS MEAN (± SD) CUMULATIVE TIME FOR (a) 1 m CONTOUR UPSTREAM RELEASES (b) 3 m CONTOUR UPSTREAM RELEASES (c) 7m CONTOUR UPSTREAM RELEASES (d) 1 m AND 3 m CONTOUR DOWNSTREAM RELEASES AND WITHIN DISCHARGE RELEASE. MEANS ARE FOR 3 DRIFT TUBES. LEGEND INDICATES APPROXIMATE DISTANCE OF RELEASE POINTS FROM DISCHARGE CENTRELINE

were about 1200 m north of the end of the discharge groin (Figure 5), the mean drift tube speed was similar to that of the ambient current, suggesting that the 7 m drift tubes were no longer within the influence of the thermal plume. The mean speeds of tubes released at the 1 m and 3 m contours also appeared to approach that of the ambient (7 m contour) current by the end of the respective trials (Figure 6). Excluding initial alongshore travel time it is estimated that drift tubes released inshore along 1 m and 3 m contours were displaced offshore (to final tracking locations) by the thermal plume over a period of time ranging from 50 - 80 min, and over a distance of about 900 - 1200 m. The entire duration of separate drift tube trials ranged from 80 - 130 min (Figure 6).

Downstream and Discharge Releases

The mean speed of movement of drift tubes released at the 1 m contour downstream of the discharge remained close to that of the ambient current. In contrast, the mean speed of drift tubes released at the 3 m contour increased during the middle portion of the trajectory (possibly due to plume entrainment) and eventually reached a level similar to that of drift tubes released upstream of the discharge along the 3 m contour (Figure 6). The duration of the 3 m contour downstream trial was about 145 min.

Drift tubes released within the discharge were intially displaced rapidly offshore at a mean speed of almost 60 $cm \cdot s^{-1}$. Subsequent mean speed dropped to between 14 and 22 $cm \cdot s^{-1}$, reflecting the reduced speed of the thermal plume across the mouth of Baie du Dore (Figures 4 and 6).

D. Biological Implications of Results

If artificial drifting devices adequately simulate the movement of littoral drift fish larvae, then the results of this study imply that such larvae would be transported offshore along a convergence zone formed by the upstream boundary of the Bruce GS 'A' thermal plume and a northeast longshore current. The necessity of designing drift tubes that were positively buoyant prevented the examination of subsurface phenomena. Drift tubes would not properly represent larval fish movement if some fish larvae were drawn below the water surface due to turbulent mixing of plume and lake water masses. However, mixing was not observed at the upstream boundary of the plume, suggesting that drifting fish larvae would remain near the water surface during offshore transport.

An important consequence of the offshore displacement of fish larvae could be an increase in the number of larvae occurring within the convergence zone per unit time relative to adjacent

lake surface areas. The density of fish larvae in the convergence zone could be elevated if fish larvae originating from different contours pass a given point in the zone simultaneously as suggested by the observed drift tube trajectories (Figure 5). A further increase in larval fish density in the convergence zone would occur if a larval fish concentration gradient (with high concentrations close inshore) existed upstream of the thermal plume. Thus littoral drift fish larvae could be both displaced offshore and concentrated by the Bruce GS 'A' thermal plume.

4.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results obtained the following conclusions were reached:

1. The Bruce GS 'A' thermal plume caused the offshore displacement of drift tubes (up to 900 m offshore) released upstream of the plume during a northeast longshore current. Further offshore displacement was possible but not recorded.

2. Mean distance of offshore displacement was inversely related to the distance that drift tubes were released from shore.

3. Drift tube trajectories (upstream releases) were strongly influenced by shifts in the direction of ambient lake current, which in turn corresponded to the prevailing wind direction.

4. Drift tube speeds were determined by a combination of plume and lake current speeds. Close inshore the plume influence predominated while farther offshore the lake current was more important.

5. For the tracking periods observed, the duration of offshore displacement of drift tubes was about 50 - 80 min; corresponding displacement distances ranged from about 900 - 1200 m.

6. Drift tubes were advected offshore in clusters along paths occurring within the zone of convergence of the ambient surface lake current and the upstream edge of the thermal plume. Spatial and temporal dispersion of drift tubes occurred after the initial offshore displacement phase.

Further development of a generic model to predict the offshore displacement of fish larvae should consider the above conclusions. For example, concentration contours predicted for upstream releases by the Raithby model (Raithby, 1984) may differ when the observed offshore streaming effect

(conclusion 6) is taken into account. The initial model simulations were presented as steady state phenomena incorporating a specified set of constant wind and current conditions (Raithby, 1984). This procedure does not allow for shifts in wind and current direction and speed, which altered drift tube trajectories in the present study (conclusion 3). It should be feasible to run the model in an interval mode, obtaining grid cell concentrations of larvae at successive time steps associated with discrete sets of physical conditions.

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Approved by:

O.A. Kupcis
Manager
Chemical Research Department

Prepared by:

for W.E. Carey
Biologist
Biological Research Section

Reviewed by:

G.L. Vascotto
Section Head
Biological Research Section

WEC:lg

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APPENDIX 1

DISTANCE (D), TIME (T) AND SPEED (S) DATA FOR EACH TRACK SEGMENT
NB - distances are in metres, time in seconds and speed in $cm \cdot s^{-1}$

Distance from Discharge (m)	Tube No	Track Segments (A - F)																	
		A			B			C			D			E			F		
		D	T	S	D	T	S	D	T	S	D	T	S	D	T	S	D	T	S
1 m CONTOUR UPSTREAM RELEASES																			
50	1	117	960	12.2	33	480	6.9	383	1560	24.6	142	540	26.3	583	1620	36.0	725	2280	31.8
	2	117	960	12.2	33	480	6.9	367	1500	24.5	50	540	9.3	617	1860	33.2	850	2520	33.7
	3	117	960	12.2	33	480	6.9	367	1500	24.5	117	540	21.7	550	1620	34.0	800	2640	30.3
100	1	217	1620	13.4	200	900	22.2	208	900	23.1	317	1380	23.0	425	1440	29.5			
	2	217	1620	13.4	200	900	22.2	208	900	23.1	333	1260	26.4	533	1680	31.7			
	3	217	1620	13.4	200	900	22.2	208	900	23.1	317	1380	23.0	425	1440	29.5			
150	1	167	1680	9.9	983	3720	26.4												
	2	167	1680	9.9	1067	3840	27.8												
	3	167	1680	9.9	583	3360	17.4												
150	1	33	660	5.0	167	1440	11.6	83	720	11.5	317	1380	23.0	175	960	18.2	692	2100	33.0
	2	33	660	5.0	167	1440	11.6	83	720	11.5	400	1140	35.1	317	1500	21.1	633	2160	29.3
	3	33	660	5.0	167	1440	11.6	83	720	11.5	400	1140	35.1	367	1560	23.5	617	2160	28.6
3 m CONTOUR UPSTREAM RELEASES																			
50	1	75	1200	6.3	75	960	7.8	150	600	25.0	217	840	25.8						
	2	75	1200	6.3	75	960	7.8	150	600	25.0	217	840	25.8	608	2400	25.3			
	3	75	1200	6.3	75	960	7.8	100	600	16.7	167	1020	16.4	483	2040	23.7			
100	1	133	960	13.9	92	840	11.0	325	1440	22.6	450	1740	25.9						
	2	133	960	13.9	92	840	11.0	300	1560	19.2	583	1860	31.3						
	3	133	960	13.9	92	840	11.0	300	1560	19.2	433	1560	27.8						
150	1	217	1740	12.5	150	780	19.2	333	1140	29.2	783	2580	30.3						
	2	217	1740	12.5	150	780	19.2	333	1140	29.2	1034	3180	32.5						
	3	217	1740	12.5	150	780	19.2	333	1140	29.2	1017	3000	33.9						
150	1	33	660	5.0	150	1440	10.4	133	900	14.8	83	1080	7.7	183	960	19.1	683	2160	31.6
	2	33	660	5.0	150	1440	10.4	117	900	13.0	150	780	19.2	342	1620	21.1	667	2160	30.9
	3	33	660	5.0	150	1440	10.4	133	900	14.8	83	1080	7.7	183	960	19.1	692	2340	29.6

APPENDIX 1 (cont'd)

DISTANCE (D), TIME (T) AND SPEED (S) DATA FOR EACH TRACK SEGMENT
NB - distances are in metres, time in seconds and speed in $cm \cdot s^{-1}$

Distance from Discharge (m)	Tube No	Track Segments (A - G)																					
		A			B			C			D			E			F			G		
		D	T	S	D	T	S	D	T	S	D	T	S	D	T	S	D	T	S	D	T	S
7 m CONTOUR UPSTREAM RELEASES																							
50	1	133	420	31.7	250	660	37.9	267	840	31.8	200	600	33.3	292	840	34.8	333	1320	25.2				
	2	133	420	31.7	242	600	40.3	283	900	31.4	200	600	33.3	283	960	29.5	192	720	26.7	75	180	41.7
	3	133	420	31.7	242	600	40.3	267	720	37.1	183	720	25.4	275	960	28.6	250	780	32.1	75	300	25.0
100	1	167	480	34.8	267	780	34.2	200	720	27.8	325	960	33.9	242	720	33.6	392	1380	28.4			
	2	167	480	34.8	267	780	34.2	267	780	34.2	267	780	34.2	233	720	32.4	450	1560	28.8			
	3	167	480	34.8	267	780	34.2	200	720	27.8	367	900	40.8	208	720	28.9	450	1800	25.0			
150	1	142	600	23.7	283	840	33.7	233	660	35.3	300	900	33.3	217	720	30.1	317	1080	29.4			
	2	142	600	23.7	283	840	33.7	233	660	35.3	300	900	33.3	217	720	30.1	317	1080	29.4			
	3	142	600	23.7	283	840	33.7	300	720	41.7	242	780	31.0	258	720	35.8	275	1080	25.5			
150	1	158	1020	15.5	83	1200	6.9	400	900	44.4	300	1260	23.8									
	2	158	1020	15.5	83	1200	6.9	400	900	44.4	300	1260	23.8									
	3	158	1020	15.5	83	1200	6.9	400	900	44.4	300	1260	23.8									
DOWNSTREAM RELEASES																							
100 (1 m Contour)	1	175	2700	6.5	133	1920	6.9																
	2	208	2520	8.3	167	1740	9.6																
	3	208	2520	8.3	167	1740	9.6																
150 (3 m Contour)	1	308	3120	9.9	242	1080	22.4	600	2040	29.4	625	2400	26.0										
	2	308	3120	9.9	242	1080	22.4	600	2040	29.4	583	2280	25.6										
	3	308	3120	9.9	275	1200	22.9	633	2040	31.0	683	2820	24.2										
DISCHARGE RELEASE																							
-	1	317	540	58.7	167	780	21.4	300	2280	13.2	217	900	24.1										
	2	317	540	58.7	200	960	22.2	233	1860	12.5	150	660	22.7										
	3	317	540	58.7	158	720	21.9	300	1920	15.6	225	1680	13.4										

APPENDIX 2

MEAN DRIFT TUBE SPEED AND MEAN CUMULATIVE TIME DATA

- Values are ± SD; Mean Speed ($\bar{S}$) in $cm \cdot s^{-1}$; mean time ($\bar{T}$) in seconds

Distance from Discharge (m)		Track Segments (A - G)						
		A	B	C	D	E	F	G
1 m CONTOUR UPSTREAM RELEASES								
50	$\bar{S}$	12.2 ± 0.0	6.9 ± 0.0	24.5 ± 0.1	19.1 ± 8.8	34.4 ± 1.4	31.9 ± 1.7	-
	$\bar{T}$	960 ± 0	1440 ± 0	2960 ± 35	3500 ± 35	5200 ± 125	7780 ± 69	-
100	$\bar{S}$	13.4 ± 0.0	22.2 ± 0.0	23.1 ± 0.0	24.1 ± 2.0	30.2 ± 1.3	-	-
	$\bar{T}$	1620 ± 0	2520 ± 0	3420 ± 0	4760 ± 69	6280 ± 69	-	-
150	$\bar{S}$	9.9 ± 0.0	23.9 ± 5.6	-	-	-	-	-
	$\bar{T}$	1680 ± 0	5320 ± 250	-	-	-	-	-
150	$\bar{S}$	5.0 ± 0.0	11.6 ± 0.0	11.5 ± 0.0	31.1 ± 7.0	20.9 ± 2.7	30.3 ± 2.4	-
	$\bar{T}$	660 ± 0	2100 ± 0	2820 ± 0	4040 ± 139	5380 ± 193	7520 ± 227	-
3 m CONTOUR UPSTREAM RELEASES								
50	$\bar{S}$	6.3 ± 0.0	7.8 ± 0.0	22.2 ± 4.8	22.7 ± 5.4	24.5 ± 1.1	-	-
	$\bar{T}$	1200 ± 0	2160 ± 0	2760 ± 0	3660 ± 104	5910 ± 127	-	-
100	$\bar{S}$	13.9 ± 0.0	11.0 ± 0.0	20.3 ± 2.0	28.3 ± 2.7	-	-	-
	$\bar{T}$	960 ± 0	1800 ± 0	3320 ± 69	5040 ± 139	-	-	-
150	$\bar{S}$	12.5 ± 0.0	19.2 ± 0.0	29.2 ± 0.0	32.2 ± 1.9	-	-	-
	$\bar{T}$	1740 ± 0	2520 ± 0	3660 ± 0	6580 ± 308	-	-	-
150	$\bar{S}$	5.0 ± 0.0	10.4 ± 0.0	14.2 ± 1.0	11.5 ± 6.6	19.8 ± 1.2	30.7 ± 1.0	-
	$\bar{T}$	660 ± 0	2100 ± 0	3000 ± 0	3980 ± 173	5160 ± 208	7380 ± 180	-
7 m CONTOUR UPSTREAM RELEASES								
50	$\bar{S}$	31.7 ± 0.0	39.5 ± 1.4	33.4 ± 3.2	30.7 ± 4.6	31.0 ± 3.4	28.0 ± 3.6	33.4 ± 11.8
	$\bar{T}$	420 ± 0	1040 ± 35	1860 ± 104	2500 ± 35	3420 ± 60	4360 ± 277	4440 ± 85
100	$\bar{S}$	34.8 ± 0.0	34.2 ± 0.0	29.9 ± 3.7	36.3 ± 3.9	31.6 ± 2.4	27.4 ± 2.1	-
	$\bar{T}$	480 ± 0	1260 ± 0	2000 ± 35	2880 ± 60	3600 ± 60	5180 ± 193	-
150	$\bar{S}$	23.7 ± 0.0	33.7 ± 0.0	37.4 ± 3.7	32.5 ± 3.3	32.0 ± 2.2	28.1 ± 2.3	-
	$\bar{T}$	600 ± 0	1440 ± 0	2120 ± 35	2980 ± 35	3700 ± 35	4780 ± 35	-
150	$\bar{S}$	13.5 ± 0.0	6.9 ± 0.0	44.4 ± 0.0	23.8 ± 0.0	-	-	-
	$\bar{T}$	1020 ± 0	2220 ± 0	3120 ± 0	4380 ± 0	-	-	-
DOWNSTREAM RELEASES								
100 1 m Cont	$\bar{S}$	7.7 ± 1.0	8.7 ± 1.6	-	-	-	-	-
	$\bar{T}$	2580 ± 104	4380 ± 208	-	-	-	-	-
100 3 m Cont	$\bar{S}$	9.9 ± 0.0	22.6 ± 0.3	29.9 ± 0.9	25.3 ± 0.9	-	-	-
	$\bar{T}$	3120 ± 0	4240 ± 69	6280 ± 69	8760 ± 352	-	-	-
DISCHARGE RELEASE								
-	$\bar{S}$	38.7 ± 0.0	21.8 ± 0.4	13.8 ± 1.6	20.1 ± 5.8	-	-	-
-	$\bar{T}$	540 ± 0	1360 ± 125	3380 ± 211	4460 ± 421	-	-	-